"Multiscale Modeling, Analysis, and Simulation of Preferential Flow"

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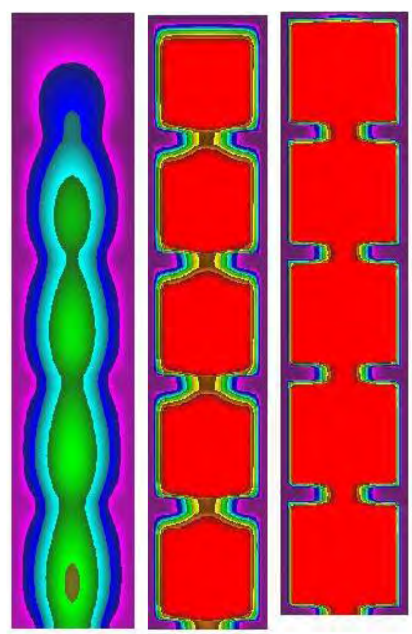
Summary

Natural porous media exhibit extreme heterogeneity over a multitude of scales and the mainstream view of flow phenomena in porous media considers fixed and strongly-separated length scales. Recent research by the Multiscale Research Group at OSU yields the capability to model flow phenomena in porous media over a range of not well separated scales with a focus on problems of preferential flow and transport in porous media.

We are developing methods to *blend* the scale separation and describe processes over a range of scales with a focus on model problems of **preferential flow** in porous media. This has enormous importance for management and clean-up of nuclear and other industrial waste sites. At the same time, it presents a formidable challenge for multiscale multiphysics modeling, analysis, and numerical approximation.

Preferential flow occurs in natural porous media such as soils and bedrock due to the presence of unusually large connected pores or fast flow channels in which fluids flow at velocities much higher than the filtration velocities in the surrounding porous material. Classical approaches to modeling preferential flow and contaminant transport include double-porosity models which extend Darcy and Fickian models of saturated flow and advective-diffusive transport and Richards equation for unsaturated flow. The main premise in these is that flow and transport in fast and slow flow regions is coupled by local equilibrium interface conditions and that full scale separation of scales exists between the fast and slow regions. However, some of the delay effects in response to dynamic transient inputs known as tailing behavior, cannot be described by any of the existing models.



Challenge of various flow scales and associated transport.

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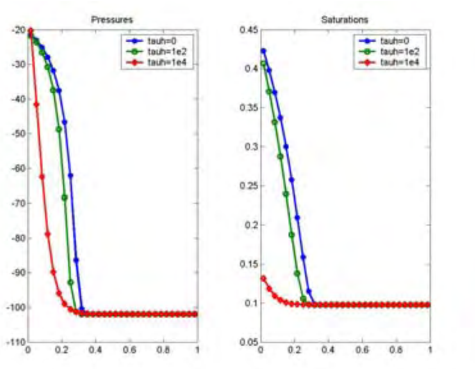
Our recent results include i) pore-scale computational modeling of non-Darcy flow, ii) non-local multiscale models for transport, iii) non-equilibrium and dynamic capillary pressure models for unsaturated flow, and Brinkman-like models of fast channel flow along the interface of a porous medium with a solid. Here the lower dimension of the surface forces most of the fluid to flow near the porous medium, so it develops the required drag forces which account for the Darcy-like terms added to the Stokes system.

Our models as in ii) perform as well as the classical models in the low-contrast range and the two-scale models in the high-contrast range, and moreover they yield the observed effects over a very wide range of conditions and parameter values and mixing scales. Additionally, these new models are mass conserving, contain the effects of local advective transport, and they are the first to capture the break-through concentration profiles throughout the entire range of contrast.

The motivation for iii) came from recent experimental evidence on fast preferential flow which indicates that the capillary pressure function is not uniquely determined when large flow rates are present. The OSU group has developed new models of dynamic capillary pressure in two-phase flow models based on CCFD and LCELM, and early indications are that these will perform better than the traditional equilibrium models.



Effects of dynamic capillary pressure

The **Workshop on "Modeling, Analysis and Simulation of Multiscale Nonlinear Systems"** was held at Oregon State University, June 25-29, 2007.
The workshop brought together an interdisciplinary group of scientists working on various aspects of nonlinear coupled phenomena occurring at multiple spatial and temporal scales in natural and man-made environments. The Program included general overview talks on methods and applications as well as special topics including modeling of preferential fluid flow and transport, experiment-based and computational porescale-to-watershed modeling, analysis of multiscale nonlinear PDEs systems as well as stochastic approaches, adaptive multiscale computational techniques and their implementations, biological and engineering applications with multiscale character.

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